

**Clean Coal Technology**  
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**Week-01**  
**Lecture-02**

Hi, I am Professor Barun Kumar Nandi. Welcome you back on this NPTEL online certification course on Clean Coal Technology, Module 1, Lecture 2. So, we'll start from the last class, where we ended with the origin of coal. Now in this lecture, we'll know the different properties of coal or different ways to characterize our coal or different ways to identify the coal properties. So based on the types of hydrocarbon present in coal, there are combustible part of coal, which is classified as volatile material and fixed carbon. And from the first class, we know that coal contains combustible part. They are hydrocarbon part of this coal. Now this hydrocarbon part of this coal are differentiated further as two categories. One is known as the volatile material or VM and second category is known as the fixed carbon or FC.

Typically, volatile material represents highly volatile hydrocarbons, mostly low molecular weight hydrocarbon present in coal. So, if we see the hydrocarbon present in coal, they are of different molecular weights. As their different molecular weights are there and accordingly their number of carbon compounds or carbon content is varied. Broadly as coal originates from the trees or plants and their hydrocarbon. It can have maybe carbon content about 100. So out of this 100 carbon content compound, there are some compounds we start from maybe C1 to C10 like these compounds. So similar type of compounds which are of low molecular weight. So, these compounds are categorized as the volatile material.

So, there is not any particular differentiation like it is C10 or C1. This is just like an imaginary concept to identify that the low molecular weight hydrocarbons are there. We will call them as volatile material because they will have low molecular weight and accordingly as their molecular weight, it is linked with their boiling point. Typically, low molecular weight means their boiling point is less and they can easily release from the coal surface when we heat them. So, these type of hydrocarbons, we call them as the volatile material whereas the compounds like C30 to C100. They will have boiling point very high. So such compounds will not be released from the coal surface when we heat them. So, these compounds are in broad, we call them as the fixed carbon or FC. So, difference between this fixed carbon and volatile material is their types of molecules presence or types of hydrocarbon presence. So, these hydrocarbons which release from the coal surface at lower temperature, around 925 degree centigrade if we heat the coal in absence of air for 7 minutes, we call them as volatile material. This is an internationally accepted or internationally known definition of volatile material. So, in laboratory, there are some particular methods to analyse the volatile material of coal. When we analyse the volatile material of coal. Coal is taken in a crucible or in a container in a crucible. We fill with their coal and we put a lid. So, when we put this lid, it prevents any oxygen going there. So, in the absence of oxygen, coal will be heated. So, whatever the hydrocarbon, it will be released from the coal surface that mass loss corresponding to the hydrocarbons of this coal.

That will be known as the volatile material of the coal. So, these hydrocarbons which released from coal at 925 degree centigrade. Now why this 925 degree centigrade and 7 minutes are there? So, this is an overall intentionally accepted parameters to characterize the coal.

At 925 degree centigrade, Actual hydrocarbon present from the coal surface they released as well as some of the thermally heating or thermal cracking reactions also takes place and typically it completes within 7 minutes time duration. That's why this is the parameter how we analyse or how we identify the volatile material of the coal. and after heating whatever is the residual hydrocarbon present. So, whatever the residual hydrocarbons are present. Those are typically almost a carbon rich or high carbon containing compounds present. Those part is we characterize or we call them as fixed carbon. So overall there is hydrocarbon, they are constitutes of volatile material plus fixed carbon. So overall hydrocarbon part is categorized into different part. One part is volatile material which easily released from the cold surface during heating and residual hydrocarbon which doesn't release to the atmosphere or to the air during heating and they remain almost as a carbon rich or high carbon rich residue. So, they are known as the fixed carbon. And typically, volatile material they constitute much more quantity of hydrogen, oxygen, nitrogen and similar type of hydrocarbon. Typically, their molecular weight are low. Their boiling point is also low. Whereas fixed carbon contributes to the overall energy content or gross calorific value of the coal. And this volatile material as their low boiling point compounds. The low boiling point hydrocarbons, they easily mixed with air and during ignition they easily catches fire. So typically, these volatile materials help since ignition of this coal. Fixed carbon constitutes the carbon rich compounds or carbon rich hydrocarbons and in this fixed carbon, hydrogen, oxygen and nitrogen quantity is very less. Very minimum quantity or negligible quantity of hydrogen, oxygen, nitrogen and similar compounds or molecules are found in hydrocarbons and sometimes fixed carbon also contains pure carbon like only c because during this heating some of the thermally cracking or decomposition occurs due to the action of heat so as a result most of the hydrogen or hydrogen rich compound released from the coal surface by forming volatile gases like methane ethane and similar type of volatile gases releases occur which constitute that part of volatile material so residual part is known as the fixed carbon. In terms of calorific value, most of the calorific value or gross calorific value known as the GCV contributes or originates from the fixed carbon. So overall this energy content of this coal is available from both volatile material as well as the fixed carbon. Volatile material are those compounds which are easily released from the coal surface by heating and Fixed carbon are those hydrocarbon which are carbon rich and does not release from the coal surface and they will remain in the solid phase of the coal after heating. In the mineral matter, where the different type of inorganic salts of aluminium, silica, calcium, magnesium, sodium, potassium, iron and many more are metallic and non-metallic elements. So, these inorganic salts, they present in coal like sodium sulphate, potassium sulphate, aluminium chloride, silicon oxide, magnesium hydroxide etc. In different combination of inorganic and in the different combinations of different salts of all these elements are present. And during their heating, they decompose. And if the oxygen is present during their decomposition, they convert it to their individual oxides.

So, all the salts of aluminium, it is assumed that they will be converted to aluminium oxides. All the salts of silicon, calcium, magnesium, sodium, potassium, they will be converted to their

oxides like  $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$ , etc. So, this decomposition to individual oxides is called the ash formation. So, this ash constitutes all the inorganic oxides. So, there is some fundamental difference between the mineral matter as well as ash. In a mineral matter, it is as part or as actually present in the different type of clay material present in the coal. So, they contain different type of inorganic salts. Whereas in the ash, they are the residue after the combustion or after the heating. So, they are mostly oxide forms of the metal. So, by theoretical way, this mineral matter and ash are somehow different. Typically, mineral matter, when it is converted to ash it goes for 10% reduction in the weight. It is an assumption or overall experimental observation is observed that. So overall mineral matter equals to 1.1 or 1.08 ash. It is taken like sometimes; it is 1.08 times of ash or sometimes 1.1 times of ash. So mineral matter quantity is more and ash quantity is less. Like if its coal has 30 percent ash, it will assume to be like a 33 percent mineral matter. So, these are only empirical equations that vary from mine to mine and source to source. So overall when we call in a general discussion, we call mineral matter as in a similar way. But actually, there are these minor differences in there. But in actually when we call them in different application, sometimes we call it mineral matter, sometimes we call this ash. So, they are called like they are almost similar material. But in theoretically there are some differences there. Now when we discuss about the plants, which compounds are or which properties are interested for the thermal power plant and which properties are important for the steel plants. Typically, in thermal power plant, fossil fuel or coal are burned to produce steam and to produce electricity energy. So, for this thermal power plant, they are more interested in the combustible part which gives them the energy during burning or during combustion. So thermal power plants, they are interested in volatile material and fixed carbon because these two compounds give their calorific value or gross calorific value or the energy. So, for thermal power plants, they are only interested in the volatile material and fixed carbon. So, any coal having higher amount of combustible materials or hydrocarbon rich in volatile material and fixed carbon they are suitable for the thermal power plant. So, they are interested on these two parts. So, if these two parts are there obviously their gross calorific value will be on the higher side. So, for thermal power plant utilization only the volatile material and fixed carbon they have interest because these two contribute to the gross calorific value and they are not interested with the mineral matter and moisture content as they are the impurities and there are other characterizations also in the coal which is called like a coking and non-coking coal. So thermal power plants only need non-coking coal which doesn't form any coke during heating. So thermal power plants are only interested in the non-coking coal or they are called as the non-coking coal or thermal coal. Whereas in the steel plant, this coal is used to reduce the iron ore to make it  $\text{Fe}_2\text{O}_3$  to make it converted to iron. So, in this application or in the steel plant, coal is used as a carbon rich material or as a carbon rich reactant.

So, steel plants are more interested in the fixed carbon. So, they are not interested in the volatile material present in the coal. Because they need carbon content as well as they use coal to produce some of the heat to maintain the temperature inside the blast furnace. So, for steel plant they are interested only in the fixed carbon as well as in the GCV or calorific value of the coal. And obviously, they should be of the coking properties which will form coke. And that is actually the difference between the coking coal and non-coking coal or we can say the thermal

coal or metallurgical coal. In case of thermal power plant, we need non-coking coal which doesn't form any coke during heating. and in the steel plant they are only interested in the coking coal. Their non-coking coal will not do their job in the steel plants. So, for the steel plant what is requirement is that they should be able to form coke. They should have high carbon content or high fixed carbon content. They should have higher gross calorific value as Fixed carbon is there, it will always have higher amount of gross calorific value present in the coal and for them, the volatile material and mineral matter is not accepted or not desirable. So, this is their fundamental difference between their utilization in the thermal power plant as well as in the metallurgical application.

For thermal power plant, they need both fixed carbon as well as the volatile material, whereas in the steel plants, volatile material is not required they are not interested in the volatile material. They are only interested in the fixed carbon and GCV and they should have the coking properties or they should make coke Their coke or coking properties is required. to make coke with good mechanical strength and their characteristics is their caking index, free-swelling index values and LTGK characteristics. Actually, these three characteristics are analysed to identify whether coal is coking coal or non-coking coal having very good coking characteristics or swelling characteristics that is called as the coking coal. Then it is useful in the metallurgical application. If it doesn't have any such value then it is called the non-coking coal used in the thermal applications. So, this type of coal is called the metallurgical coal or coking coal where it has very good coking properties been there. And in case of cement plant, the cement plant coal is mixed with the other raw materials and heated at high temperature. So, for cement plant they are interested only in the energy content available in the coal like their gross calorific value. So, they are only interested in the GCV value of the coal. They doesn't need any other properties important like their mineral matter, fixed carbon, volatile material. They are not so much important until it has very good calorific value and they can accept very high ash coal also because the components of the mineral matter like silica, alumina They are also part of cement. In the cement, it also constitute sodium, potassium, calcium, aluminium. All are there so high ash coal is also accepted. In case of cement plants and They need high ash coal is also accepted. So, they need only good GCV coal and it should have non-coking properties.

So, the fundamental difference between the thermal coal utilized in the thermal power plant and cement plant is the acceptability of the mineral matter and volatile material. For power plant application, they need both volatile material, fixed carbon as well as GCV. Whereas in the cement plant, they are only interested in the GCV of the coal. They are not bothered about the volatile material part of coal. High ash content coal is also accepted in the cement plants, whereas in a thermal plant, they are not so much accepted. We use them, but it is expected that ash content of this coal will be less. And there are other process for production of steel or reduction of iron, that is called the direct reduce iron or DRI process, whereas in this technology, that any non-coking coal is also used to produce syngas which is used to produce iron from the iron ore. These are different technology compared to the blast furnace method for producing steel or reduction of iron ore. So, in case of direct reuse method, non-coking coal can be used.

As non-coking coal can be used in this process, this process is typically cheap now it is mostly used in different steel plants to produce iron from the iron oxides. Non-coking coal can be used in such steel plants and in case of domestic applications, we need only low calorific value coal for domestic application where for coking and similar purpose higher amount of heat is not required lower quantity of heat but continuous amount of heat is required for coking force and others so for domestic application any low gross calorific value coal or high ash coal can be used. In an Indian scenario, about 88 percent non-coking coal is there and only 12 percent coking coal is available. As there is a shortage of coking coal, that's why this price of this coking coal is on the higher side and non-coking coal price is on the lower side. As the availability of coking coal is less. The steel plants want to use non-coking coal and they are going for the DRI process compared to the blast furnace based process. For Indian scenario Coal India Limited or CIL has different subsidiaries, whereas in this BCCL and CCL have the most of the coking coal reserve and whereas the other subsidiaries has most of the non-coking coal reserve available and if we want to further analyse the difference between the coking coal and non-coking coal, there are characteristics like caking index is available. Now what is this caking index?

In this caking index analysis, we mix coal, fine powder coal with the particular type of sand and we heat them. So, during this heating, if residual material remains in a solid form, in a very good strong pellets, we call them as a coke. and we analyse them their mechanical strength, their properties is called the caking index. If it has made a very good cake, then its caking index value is high and if it does not make any good cake then its caking index value is less. Similarly, in the free swelling index values, we measure the swelling characteristics. During this analysis, if coal swells and comes to a liquid phase or semi-liquid phase or we call them as a plastic phase, then its value is higher. We call them the FSI values. So, this is also another method to identify the coking coal and non-coking coal. There is also LTGK analysis is also a similar analysis to analyse the whether it is a coking coal and non-coking coal. So, in the Indian scenario if we see what type of coal is good and what type of coal is not good and if we compare it with the international scenario if we see that in Indian case at present 30% ash coal is rarely available. Very few mines are there where we can get 30% ash coal is available. So, in Indian scenario 30% ash coal is a very good coal. It has a very high market value and high market price also and many industries want to get this coal. So, in Indian scenario 30% ash is very good coal. Whereas most of the coal mines we can find ash content in the range of 40%.

That's why it is on satisfactory level. And if any coal mines have ash or any coal ash have ash more than 50%, it is not okay. But still some coal mines or some coal seam have 50% ash is available. So, in Indian scenario, 30% ash is good or very good, 40% ash is satisfactory and above 50% is not good.

Most of the coal mines here in Indian scenario have ash content around 35 to 45%. Whereas in the world scenario or if you see the European or American scenario, their ash content in the coal is very less. So, for them 10% ash is the normal value available in the coal. And if in world scenario, 30% ash means it is a very high ash content coal. Like if you see in any European coal or if you see the Indonesian coal, Australian coal, their ash content is less than 10%. So, they are good coal in terms of when we characterize them in terms of ash. So, for them, the

30% ash is the high ash coal. Why these two part is important? Because in many applications or many discussions, we call it the high ash Indian coal or high ash coal. So, this high ash coal is a relative term. There is not any particular value. If we see the world scenario, 30% as means high as coal. But if you see in the Indian scenario, the 30% ash is very common. and in such case, 50 percent ash is the high ash coal. So, in general Indian coal is known as the high ash coal whereas in the world scenario 10 percent to 15 percent ash is very common and above 15 percent ash is known as the high ash coal and if we see in the first further In the northeast coal, there are different states are there like Assam, Meghalaya, Nagaland, Manipur, Arunachal Pradesh, etc.

There are different coal mines are available under the Coal India Limited. And this coal has a very specific properties of having higher amount of sulphur. So, their sulphur content is very high in the range of 4 to 10%. There are different literatures are available, different coal mines are available. Some of the coal mines can have ash content is less. So typical characteristics of the northeast coal is that they have very good gross calorific value, very good coking properties. But they have very high sulphur content. As sulphur is a major impurity present in the coal apart from mineral matter. So, this coal is not useful for none of the applications in the previously stated. In northeast coal has very low ash content six to seven percent ashes they are almost in line with the European coal on Australian coal but the major problem is that they are high sulphur content, so although their calorific value coking properties, all are there due to their sulphur content such coals are not useful at all and to meet the overall demand India import coal from different countries like Australia, South Africa, Indonesia and others because in Indian scenario, we depends on coal per most of the power generation. So apart from thermal power generation, there is a scarcity of coking coal shortage. As only 12% coking coal is available in Indian scenario. So, India imports large amount of coking coal from the different countries as well as to meet the peak demand in summer and other season, some of the non-coking coal are also imported from all these countries. and overall scenario that cement plant, they can only use the high sulphur coal to some extent. So, acceptability of high sulphur coal is limited to the cement plant because in the cement plant in their production process they produce calcium sulphate or they use calcium sulphate or gypsum as part of cement so this high sulphur if it is converted to calcium sulphate or gypsum then it is a part of cement. So, due to this reason, cement plant can accept to some extent high sulphur coal, but it is limited to their design. If in their design they can accept high sulphur coal, then it is only accepted. And due to high end applications and demand, coking coal are typically costly, about Rs. 10,000 to 15,000 per ton.

As India have only 12% of coking coal reserve and the market value of the produce steel is on higher. So, steel production application means it is a high end utilization of coal. So, any coking coal, their market value is on the higher side. So, it is on higher side, maybe 10,000 to 15,000 rupees per ton. Actual value is market dependent. Its value depends on other parameters and as per the government guidelines. But coking coal price is on the higher side. Whereas in the non-coking coal, their application is only to produce the energy content. So, it is not like a higher applications of coal. So, their market value is on the lower side. So typically, their market value may be on the rupees 4000 to 6000 per tonne. So coking coal market value is on the higher side, non-coking coal market value is on the lower side and actual value is on the market

dependent and also the world scenario and one cost of import of coal and many other parameters, these only the tentative values on the pricing of coal. Overall coking coal are costly; they are used in the high-end application for producing steel. Non-coking coal, they are not so costly their utilization is for the mostly for the power production as well as for the cement plant and this actual cost is on the market dependent values. So, if we conclude from the past two lecture. Lecture one and lecture two if we conclude that we know or we have discussed about the origin of coal that is Actual plants converted to coal determines the types of hydrocarbon present in coal and this coalification process is also important to deciding the final coal properties.

Based on origin of the coal, these coal properties or coal characteristics varies. Based on origin of coal, coal characteristics varies across coal mines, inside the same mines, location, country, etc. And particularly if we know these parameters like inside the coal mines, this infers that coal extracted today may not be same properties like coal will be extracting tomorrow or coal was is extracted yesterday so there will be always some variations. Variations can be minor in range, but there is always some variations are expected. Because not every seam will be extracted in the same day or each day.

So based on origin of coal, coal characteristics varies across the mines, inside the mines which are known as the coal seam, location, country etc. Soil or clay characteristics also varies across the mines and across the coal seams. Coal are classified as non-coking coal or thermal coal whereas India has around 88% of coal reserves for thermal coal and coking coal remaining 12% is approximately the coking coal reserves. Steel industry needs high carbon, low ash, coking coal and power plant needs high GCV coal. And for textbook purpose or reading purpose as there is no specific textbook available for this. We will be following these two textbooks- fuel and combustion by Professor Samir Sarkar and fuel furnace and refractories by Dr. O.P. Gupta. So, these two textbooks will be used as a textbook as well as reference book for the entire course as well as some of the online literature or journal papers will be followed as a part of textbook or reference book.

Thank you.